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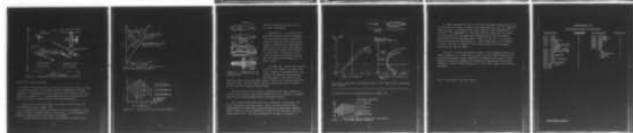
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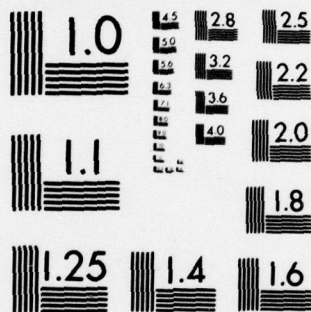
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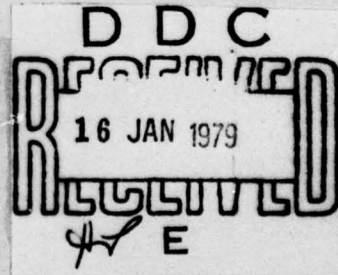
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NEW FLIGHT PROFILES

by

Zdzislaw Brodzki



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NEW FLIGHT PROFILES

Zdzislaw Brodzki

A discussion of the newest supercritical profiles for transonic airplanes, the GA(W) profile for light airplanes as well as the Liebeck profile for the lightest aircrafts is given in this article. Besides this the article also gives the description of the designed profiles for the blades of helicopter rotors. The examples of the employment of mathematical machines for studies are also given.

The steady development of all branches of aviation in recent years has caused a demand for new flight profiles. Stagnation was a characterizing factor in this field until a special study program which came into being in the USA brought new profiles. Many streamlined problems have not been completely solved yet. Besides that it is necessary to verify the computations through long lasting and arduous studies in the tunnel.

The new wing profiles are the result not only of new wind tunnels with low turbulence and high Reynolds numbers but especially of theoretical achievements and the employment of mathematical machines for fast and capacious computations.

The scope of computations which are carried out on the mathematical machines embraces not only aerodynamic coefficients and designing new profiles for the above-mentioned conditions and

airplanes, but also it includes obtaining of the streaming picture of the entire airplanes.

A special group of problems where a certain progress has already been achieved is the profiles for propellers and helicopters. The helicopter profiles are connected with the unsteady flow aerodynamics.

Particular uses impose different requirements for profiles; e. g. the low-flying transonic missiles or high-altitude rockets require different profiles. Different conditions must be satisfied for exceptionally fast gliders and these conditions must differentiate from those of the short start planes which fly at high lift coefficients C_z , or, of very big transport planes requiring thick profiles (e. g. for the purpose of the cargo placement in the aircraft).

Figure 1 shows the principal groups of the profiles presently being designed and studied as well as the requirements connected with the above-mentioned profile assignment. These are:

1 - the supercritical profiles whose main advantage is an increase in the lift/drag ratio at higher Ma numbers;

2 - the thick profiles which provide a high C_z when the resistance is small, or in other words the profiles which are designated to be used on the planes which are in the flight for a long time;

3 - the profiles for slower speeds and for higher lift/drag ratio, providing better efficiency and the flight safety;

4 - the helicopter profiles for which higher C_z magnitudes (with the influence of compressibility) move to higher Ma magnitudes. These profiles make it possible to obtain better efficiency and load-carrying capacity of the employed helicopter.

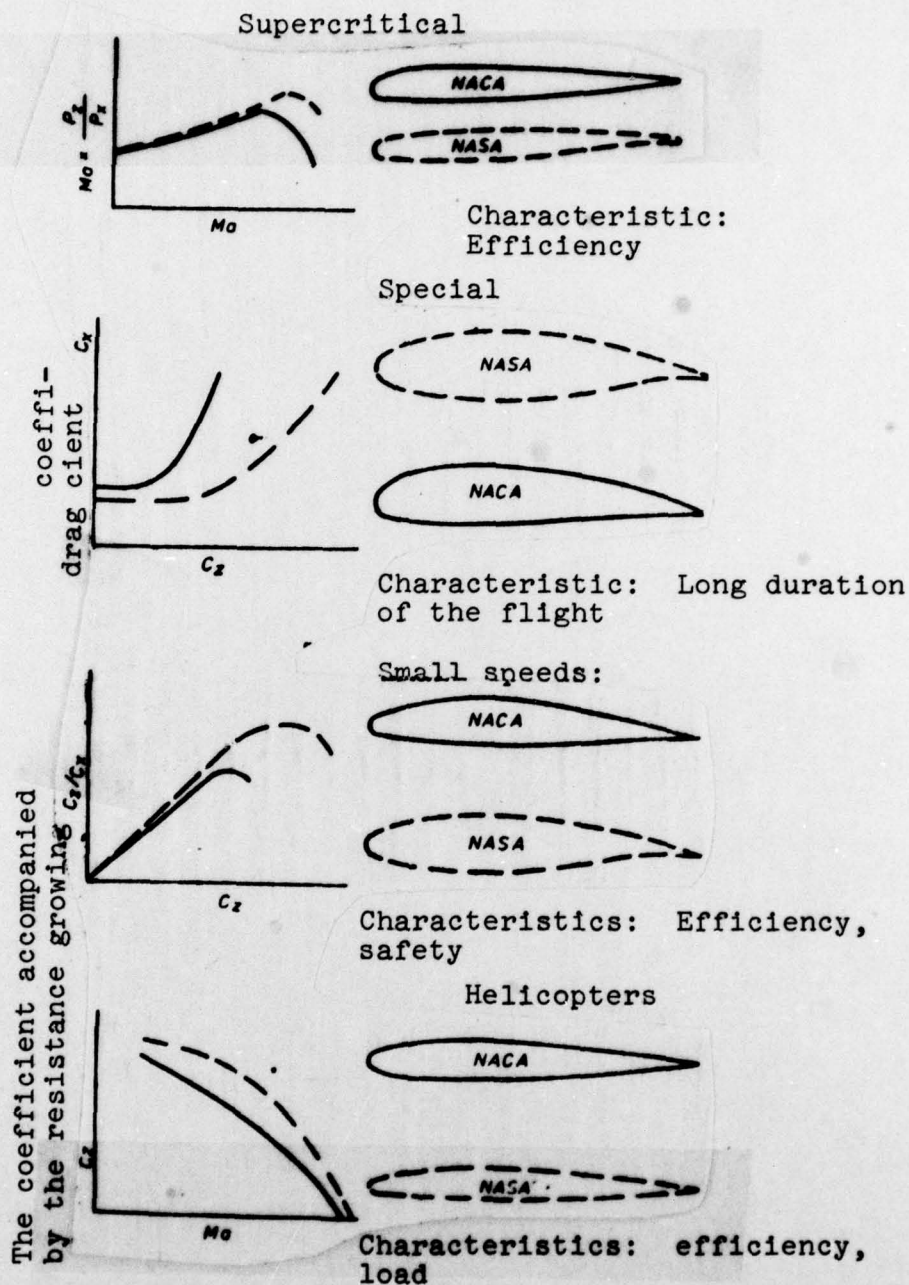


Figure 1. New flight profiles and their principal characteristics.

The work on new profiles is being carried out in many centers and many countries. Most of the publications, however, belong to NASA. The turning point has been the computation of the non-viscous flowing around the flight profile. Analytical and experimental studies brought about the analysis of the geometrical parameters. The principal parameter is the camber line, its curve connected with the value of the obtained C_z , and significant attention is being paid to the shape of the trailing edge.

The second geometrical parameter undergoing evolution is the curve of the profile nose. The camber line curve and the spot of the maximum camber along the chord determine also the moment coefficient and consequently the stability and the twisting moment which is transferred to the plane fuselage.

However, here one must take into account the difference between the so-called smooth polar curve obtained from the studies (a smooth model) and the polar curve for an actual rough aerofoil (to a greater or lesser degree) (Figure 2). It is of a special significance for the separation point which depends on slits and on the devices which are on the leading edge as well as on the Re number and the critical Ma number. As has already been mentioned above, of a special importance is verification of the computation results in a wind tunnel with appropriate parameters, although only large tunnels ensuring the possibility of the study of three dimensional flow give a chance of complete verification of the airfoil profile or helicopter blade.

The wind tunnels which are inappropriate for the studies don't produce big Re numbers and can be the reason for wrong results. They don't show the correct $C_{z \max}$ values when speeds are small (Figure 3).

There are differences in the pressure distribution (even pretty significant) according to the R_e number at transonic speeds (that is shown on Figure 4). At the critical speeds there are differences

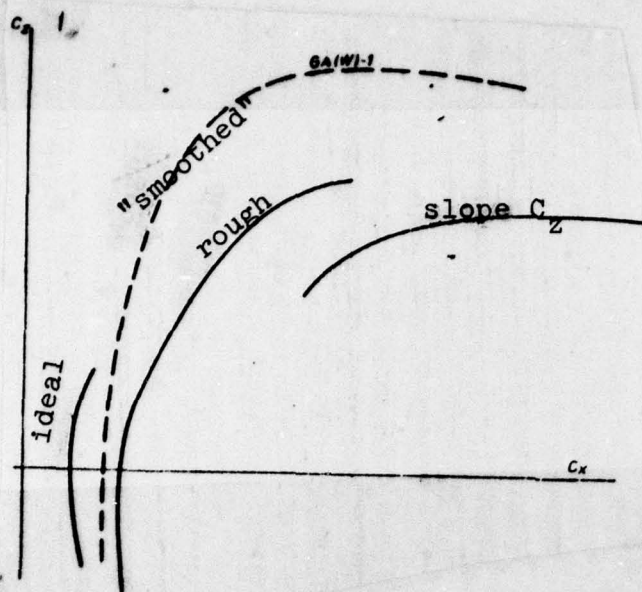


Figure 2. The smoothed polar curve and C_Z slope.

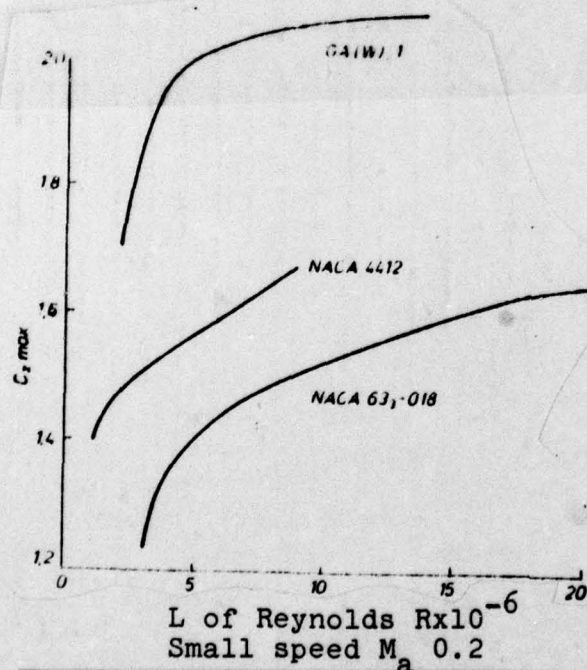


Figure 3. The Re influence on $C_{Z \max}$

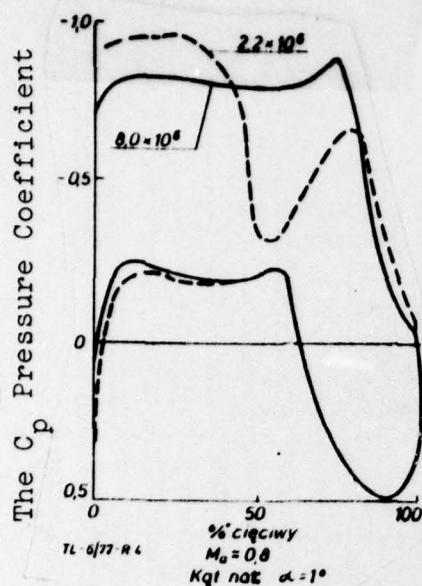


Figure 4. The Re influence on the pressure distribution on the profile.

in the pressure distribution, in the shock wave location and in aerodynamic loads. It is only a part of the existing difficulties, thus individual profile groups suitable for planes, helicopters or propellers require the wind tunnels with completely different range of the Re or Ma numbers.

The fulfillment of such different requirements is shown on the graph picturing their "satisfaction" by means of existing wind tunnels. The information which has been obtained in the direction of high speeds

(high Re and Ma) points to a certain shortcoming in the field of high-speed combat airplanes. However, in the direction of higher Re the shortcomings

of wind tunnels are even more significant. There is a lack of measuring possibilities for big transport planes as well as for propellers and small rotors for small Re's (Figure 5).

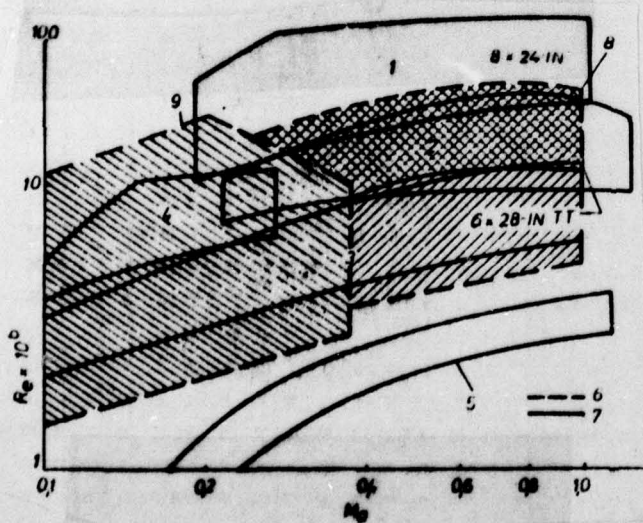


Figure 5. Operational scopes of the wind tunnels and requirements: 1 - transport airplanes; 2 - fighter planes; 3 - helicopters; 4 - light planes; 5 - propellers and tail propellers; 6 - wind tunnel limits; 7 - requirements to the planes; 8 - the cryogenic tunnels; 9 - the conventional tunnels.

As a interesting detail of the wind tunnel problems one can mention the newest trend, that is the construction of the cryogenic tunnel, in other words the tunnel operating at low temperatures. This kind of tunnel makes it possible to carry out experiments with high Ma and Re numbers although the technical difficulties of such a tunnel are significant. This tunnel will permit broadening the study range up to $Re=50$ mln and more.

The tunnel which was built in Ames (USA) whose space permits study of the short start-range plane in its full size, as well as the British tunnel with the controlled Re and Ma numbers, are a very big step ahead in this field. European industry, however, feels the shortages of wind tunnels shown in the unlined area in Figure 5, which brings the idea of construction of a big wind tunnel through international co-operation.

Supercritical Profiles

The first profile which was worked out through computations was the supercritical profile, which, as a matter of fact, had appeared before the U. S. development program came into being (Air-foil Research Program). The research and computation optimization in the years of 1950-1960 achieved a certain success. The symmetrical profile for the transonic speeds was optimized in order to decrease the wave drag (Figure 6). Through the contour modification, the critical drag which used to be obtained at $Ma=0.8$ has been obtained almost at $Ma=1.0$.

Whitcomb had designed the first supercritical profile with the reduction of the shock wave action before the transonic flow equations were settled. At present the supercritical flow computations are under control [3].

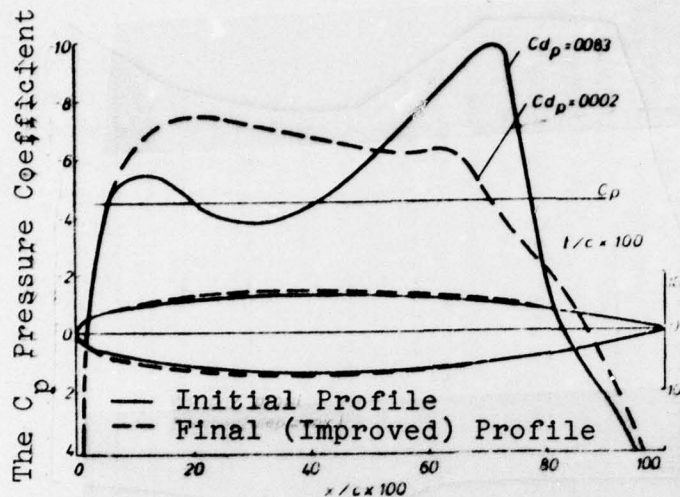


Figure 6. The profile optimization - diminishing the pressure resistance.

For the subsonic flights ($Ma=0.7-0.75$) the tran and super-sonic flow can be local (Figure 7). The characteristic of flow in the super-critical range is the shock wave departing vertically from the profile. It brings about the losses of energy and increase of drag. Besides that the

wave causes the pressure increase on the profile surface which can bring about the separation of the boundary layer and the growth of the C_z resistance coefficient. Besides the above-mentioned this wave can be accountable for vibration and as a result of this, new problems with stability and controllability of the plane will arise (Figure 7a). A more flat shape of the supercritical wing's upper surface diminishes the propagation and intensity of the shock wave (Figure 7b).

In order to compensate for the decrease of the lifting force which appears on the upper surface (the above-mentioned decrease was caused by the reduced camber), the profile has the trailing edge dropped [19].

During the flights with the $Ma=0.7-0.9$ range, the supercritical profile brings about the decrease of the structure weight because the inside reinforcements are lighter and it is also possible to diminish the wing sweep. The drag decreases and the cruising speed increases (Figure 8). The graph pictures the speed increase according to the profile thickness. It is possible to replace the conventional profile, gaining on the thickness (from 12 per cent), or, maintaining

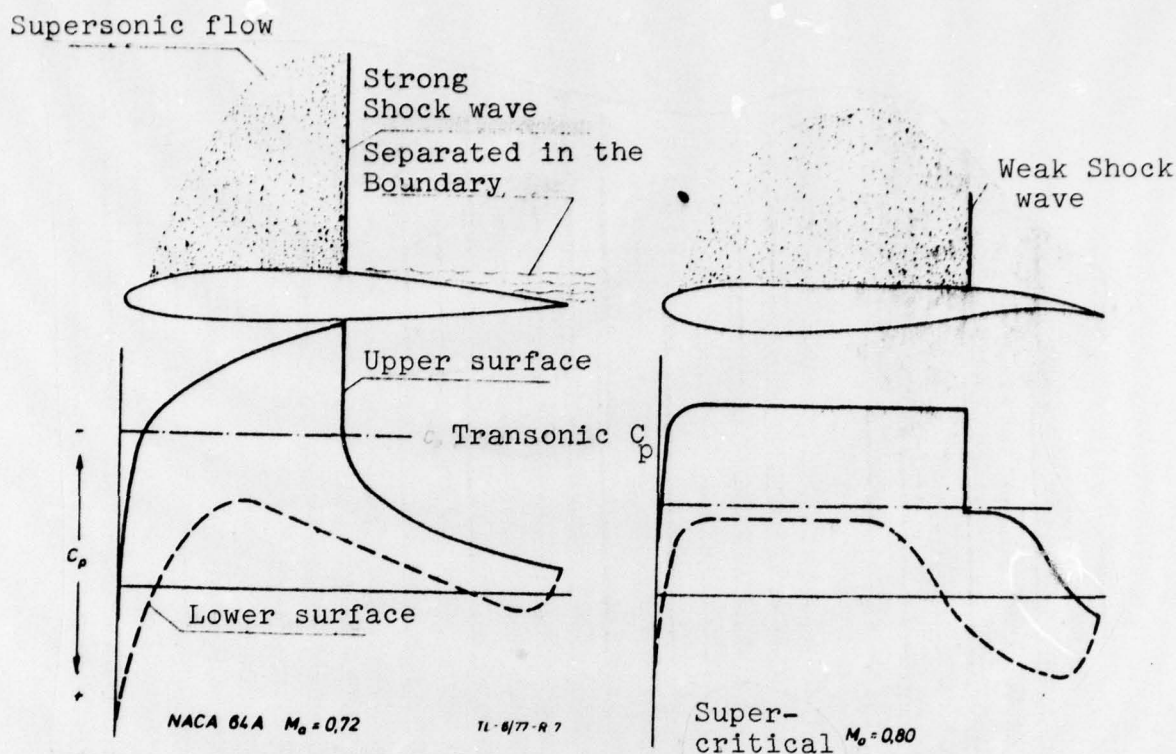


Figure 7. Physical phenomena during the supercritical flow.

the same thickness, one can gain on the cruising speed. The supercritical profile advantages become evident also at slower speeds. Due to a bigger nose radius and proper bending of the camber line (at the trailing edge) it is possible to obtain bigger $C_{z \max}$ values than under the conventional profile with displaced flaps.

The supercritical wing's susceptibility to local irregularity such as flutter or buffeting is not bigger than that of the laminar profile. Using computations and studies the scientist have worked out a whole "family" of supercritical profiles (Figure 10), and studies involving this subject are being carried out presently. The co-operation between German Federal Republic and France has brought into being the project of the supercritical profile for the improved version of the Alpha Jet [4].

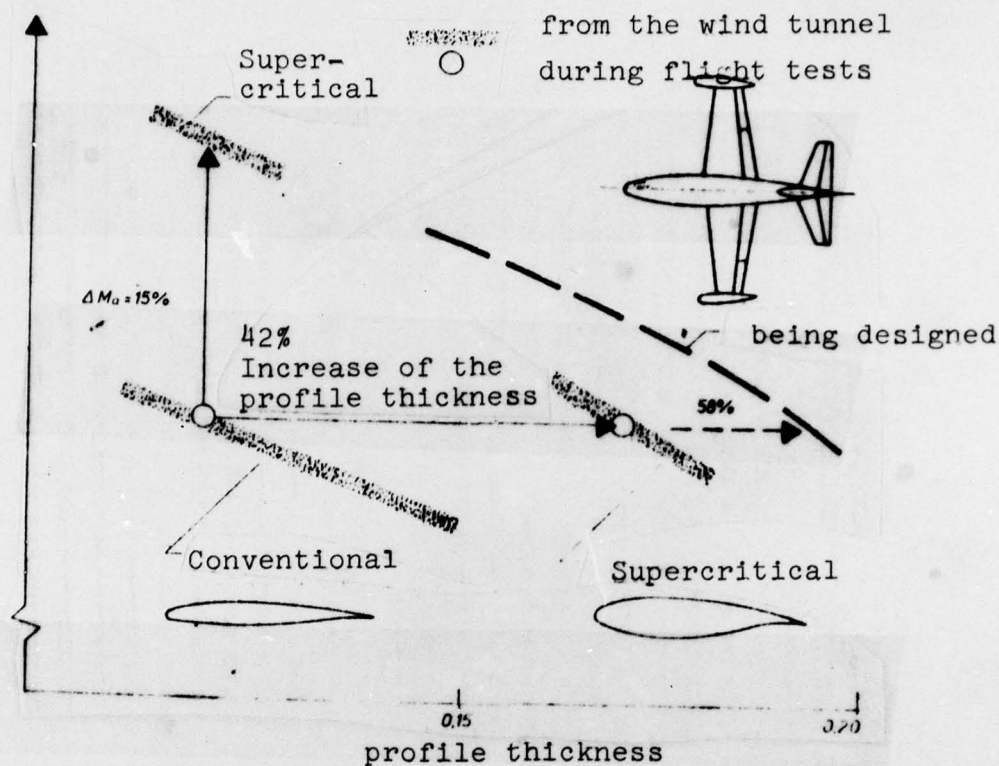


Figure 8. Employment of the supercritical profile.

Profiles for Light Airplanes

Besides the supercritical profile which came into being in 1965, of special interest is the GA(W)-1 profile designated for light airplanes. Unfortunately all its characteristics haven't been published yet (Figure 11). In comparison with the conventional profile, the GA(W)-1 profile has the following advantages:

- drag at the effective angles of attack is same as for the conventional profile (Figure 12);
- lift/drag ratio, which is almost 50 per cent higher at a big angle of attack increases safety in the case of engine damage enabling a longer glide to the place of landing;
- if flaps are not in use, the C_z increases by almost 30 per

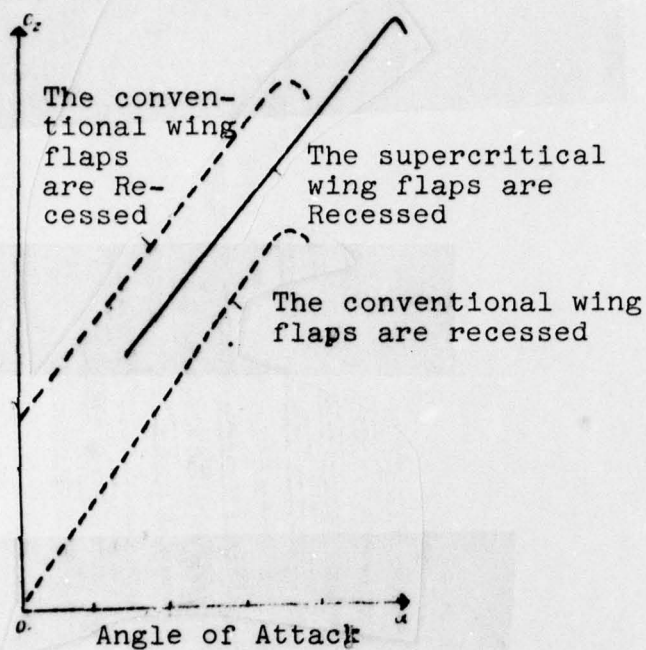


Figure 9. Comparative characteristics of the supercritical profile.

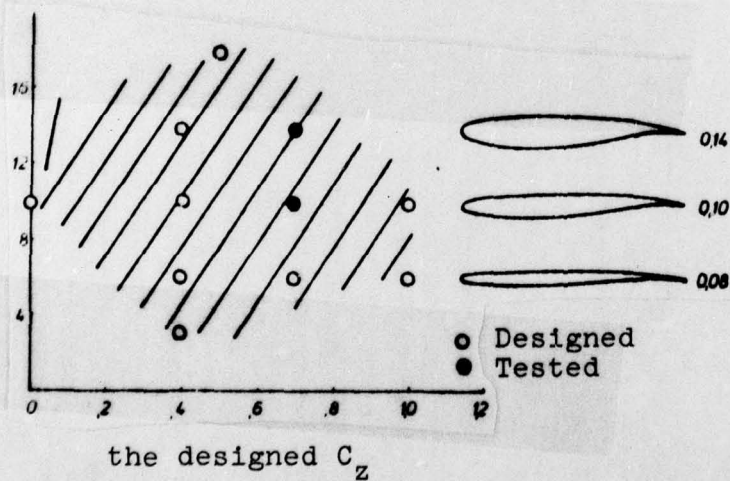


Figure 10. The supercritical profile "family".

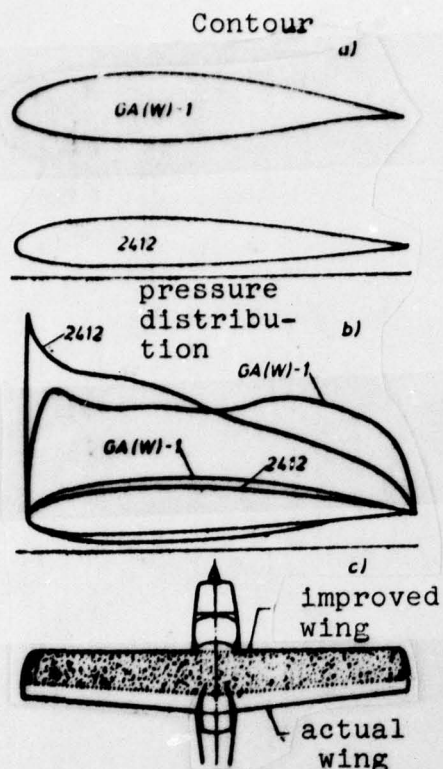


Figure 11. Comparison of the conventional profile with the improved one.

computed Fowler flaps and other simple flaps on the trailing edge have been obtained. The 12% GA(W)-2 profile turned out also to be good and was verified during testing flights.

The next phase in the profile elaboration for small speeds is to involve thin profiles, which are susceptible to the laminar separation near the thin leading edge, which can happen abruptly.

The thick profiles have also to be tested where an abrupt turbulent separation can take place. Since for most profiles with large angles of attack the separation happens on the upper surface, special studies to the mathematical model of the separation area are being carried out. The final program has to make it possible to

the flow separation on the profile is gentle and gradual.

Whitcomb (11, 17) designed his profile initially using the computation results obtained on computers. However, having a significant experience in computing the supercritical profile, he took into consideration the conditions of an actual flowing in every step of following iterations (general observations concerning the computation program will be given later).

The NASA has computed and studied a part of the "family" of these profiles (Figure 13) designated for slow speeds. In addition, experimental data relating to the profiles with

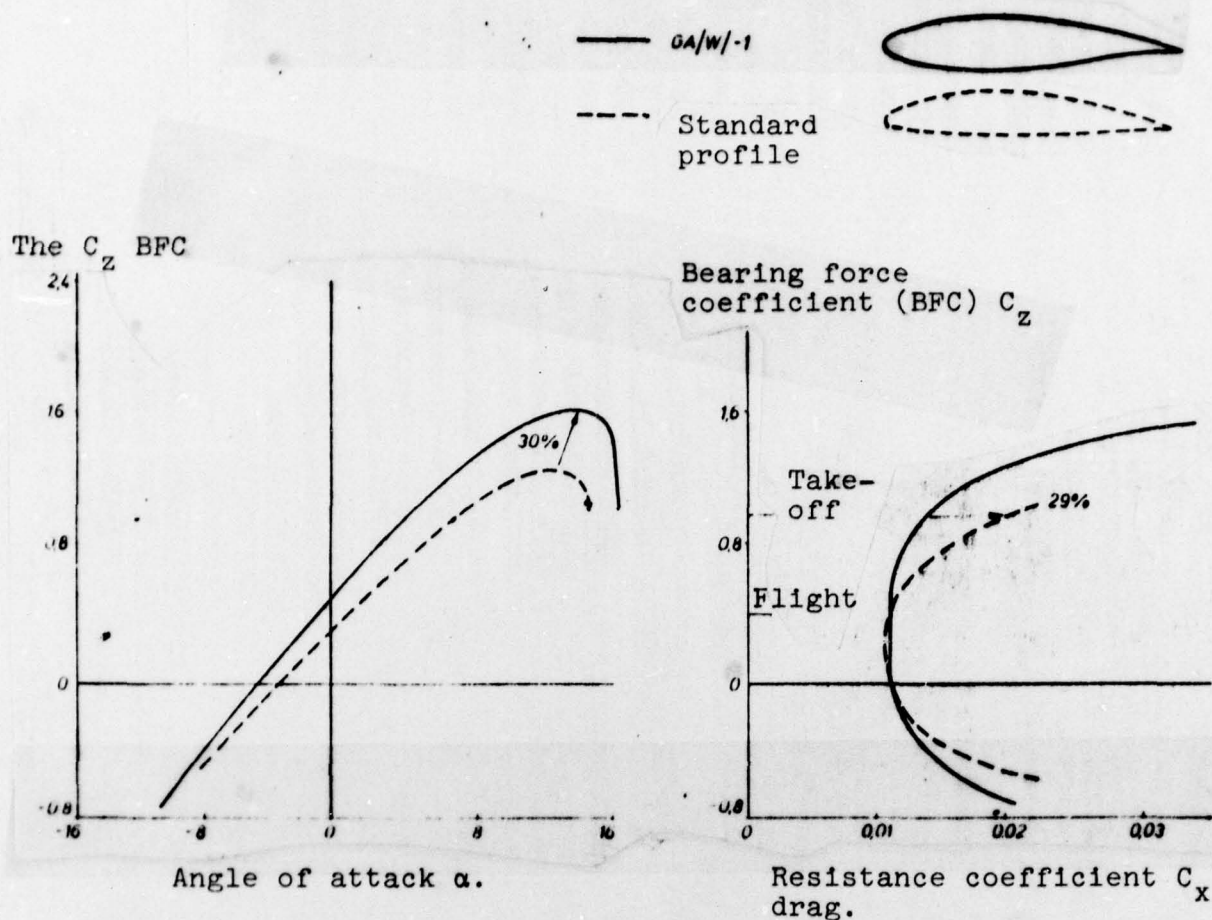


Figure 12. Comparative characteristics of the GA(W) profile (improved and standard).

design profiles in a semiautomatic way (Figure 13).

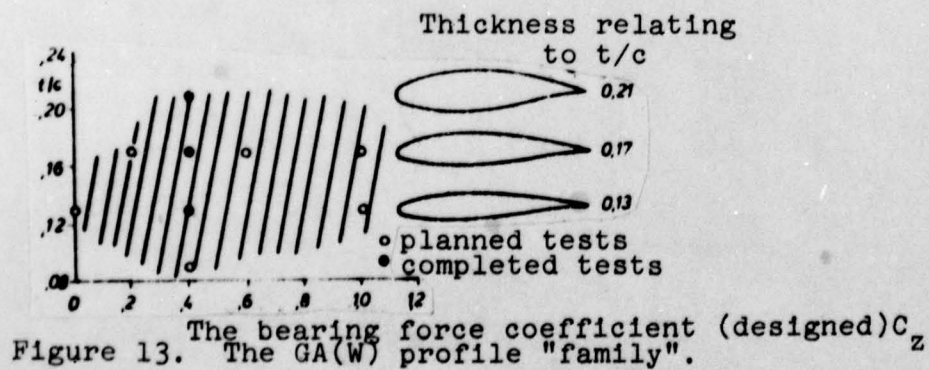


Figure 13. The GA(W) profile "family".

In light airplanes there is no threat of induced blast waves, thus the profiles don't have to have a flat upstream face like the supercritical profiles. The camber line curve has also been transferred to the back. The advantages of the GA(W) profile mostly are the result of the reduction of the negative pressure peak on the face which cooperates with the boundary layer (Figure 11 and 13). It has been achieved through the employment of a very obtuse nose of the profile in such a way that a change in the flow direction was less abrupt than when the edge is sharp.

In order to obtain the entire series of the optimal profiles for light airplanes it is necessary to spend a lot of time for scientific work and experiments which according to estimation will take 4 years. Besides the profile changes one foresees the employment of spoilers instead of ailerons and installation of the Fowler flaps on the entire wing-span.

(to be continued in the next issue)

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